

## Static modelling and analysis of updraft gasifier for 35 kW<sub>el</sub> stirling engine

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### Background

In Denmark an important step in order to replace fossil fuels with renewable energy is to incorporate the use of biomass in the electricity production system. One promising technology for using solid fuels in small scale combined heat and power plants is a gasification process combined with an internal combustion engine. Another is a stirling engine directly fueled by a biomass combustor. So far the work has been concentrated on developing each of the two technologies separately but no attempts have been made to combine the two. However, a combination presents a number of advantages. The producer gas containing tar and particles can be used directly in the stirling engine without further cleaning, and the combustion chamber of the stirling engine can be simplified and the combustion easier controlled. Furthermore development and optimisation of a heat exchanger network can improve the overall efficiency.

As a part of the national research and development programme a plant is currently being built in Ansager, Jutland, in the western part of Denmark. The plant combines an updraft gasifier with a 35 kW<sub>el</sub> stirling engine. The aim of the work of the authors is to carry out an analysis and optimisation of the system. During the work a static, mathematical model of the energy system has been developed and implemented in a suitable computer programme.

### Method of approach

The mathematical model is primarily based on energy and mass balances and consists of blocks describing the main components: Gasifier, combustion chamber where heat is transferred to the stirling engine by radiation, the convective part of the combustion chamber, the stirling engine and heat exchangers.

The updraft gasifier is modelled by using empirical data on the composition of the pyrolysis gas and by assuming equilibrium in the water gas shift reaction taking place in the gasification of the char. The gasifier sub model can thus describe different modes of operation according to the quantity of air and steam added as gasification agents, the temperature of the gasification agents, the humidity of the biomass etc.

The combustion chamber is modelled by calculating the radiation between gas and surfaces in the chamber and the convective heat transfer to the surfaces. The geometry of the chamber and characteristics of the combustion products are taken into account in the calculations. Thereby knowledge of the temperature conditions in the chamber is provided, which is important in relation to the durability of the materials and the formation of NO<sub>x</sub>.

The convective part of the combustion chamber is the outer side of the heater in the stirling engine. The heater has been developed particularly for this purpose in order to optimise the heat transfer and the geometry is complicated. The calculation of the Nusselts numbers and the convective heat transfer coefficients are therefore accordingly complicated.

The stirling engine is a separate model that differs from the rest of the system because it involves the solution of differential equations even in steady state. The differential equations describe the overall pressure in the engine, which is varying over a cycle. The output from this model is electrical power and the required heat transferred in the heater as well as heat emitted in the cooler. The required heat input is

used to control the system model. To obtain a given electrical power, the required heat transferred in the heater has to be supplied by the radiation from the combustion chamber and the convection to the outer side of the heater.

### **Use of the model and results**

The system model is used to analyse the plant in Ansager and to optimise such a plant in general for instance by investigating the influence of different heat exchanger networks on the electrical efficiency of the system. In this way the model is used to analyse a wide range of system designs and finally give a proposal for the optimal design.

It is expected that a detailed analysis of the energy flows in the system will reveal possibilities for recovering energy. The exhaust gas from the stirling engine is very hot (approximately 800°C), and the recovery of this heat is required to obtain an acceptable overall efficiency of the system.

The usual approach to increasing the system efficiency is to preheat the combustion air. Another method is to preheat the producer gas. This can imply some problems due to the high tar content in the gas. Experiments have been carried out to investigate the behaviour of condensed tar which is heated. The tar was heated to 600°C by different heat rates in an oxygen free environment. Experiments were carried out with both light and heavy tar fractions. In principal the results were independent of heat rate and type of tar. The results show that the tar losses about 90-95% of the mass and at the same time the volume is increased about 5 times. Furthermore coating, probably from guaiacol, was found on the crucible in some cases. The experiments indicate that it causes serious problems to heat exchange a gas with a content of condensed tar.

In Ansager the plant is designed to recirculate some of the flue gasses to the gasifier. This does not in itself seem like an advantage according to the efficiency, but it provides some other advantages: It raises the temperature of the producer gas and thereby it is possible to produce gas with a temperature above the dew point of the tars. In this case there should not be any problems in heat exchanging the producer gas to preheat it and thereby obtain a considerable increase of the system efficiency.

The recirculation of flue gas to the gasifier results in decreased temperatures in the combustion chamber. It then becomes possible to control the formation of  $\text{NO}_x$  and thereby meet the demands of the authorities which in the future are expected to be tightened.

In general it seems that the best efficiency is achieved by splitting the flue gas in two separate streams of which one is used to preheat the producer gas and the other is used to preheat the combustion air. Preheating of the gasification air only increases the efficiency very little – probably too little to compensate for the costs of an extra heat exchanger.

The plant in Ansager is currently in the last phase of construction, and soon the plant operation will be tested. Following this a measuring programme will be initiated to investigate the process. The results from the programme will be used to validate the model described above and, to some extent, the simulation results.